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Infrastructure Development for Regional Coupled Modeling Environments

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Infrastructure Development for Regional Coupled Modeling Environments

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Abstract

Understanding and prediction of geophysical systems have moved beyond the capabilities of single-model simulation systems into the area of multi-model multi-scale inter-disciplinary systems of interacting coupled models. This project has developed and demonstrated flexible, reusable software infrastructure for high-resolution regional coupled modeling systems that abstracts the details and mechanics of inter-model coupling behind an application program interface (API).

1. Introduction

The requirements for understanding and prediction of geophysical systems have moved beyond the capabilities of single-model simulation systems into the area of multi-model multi-scale interdisciplinary systems of interacting coupled models [3]. Terascale computing systems and high-speed grid-enabled networks are enabling high-resolution multi-model simulation at regional and smaller scales. Exploiting such capabilities is contingent, however, on the ability of users to easily and effectively employ this power in research and prediction of hurricane

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intensification, ecosystem and environmental modeling, simulation of air quality and chemical dispersion, and other problems of vital concern.

This project has developed and demonstrated flexible, reusable software infrastructure for high-resolution regional coupled modeling systems that abstracts the details and mechanics of inter-model coupling behind an API that also serves as the API to I/O and data format functionality. Knowledge of the underlying mechanisms for parallel transfer, remapping, masking, aggregation, and caching of inter-model coupling data are implemented behind the API and not within the application code itself. Thus, computer/network-specific or application-specific library implementation of the API may be substituted at link-time without modifying the application source code Developers of API implementations may be assured that their coupling software will be usable by any application that calls the API. Lastly, component models are better positioned to make use of other packages and frameworks for model coupling, such as the National Oceanic and Atmospheric Administration /Geophysical Fluid Dynamics Laboratory (NOAA/GFDL) Flexible Modeling System (FMS) and, when it becomes available, the NASA Earth System Modeling Framework (ESMF).

2. I/O and Model Coupling API Specification

The I/O and Model Coupling API specification is an extension of the Weather Research and Forecast (WRF) I/O API specification developed as part of the Advanced Software Framework developed under the WRF model project [8]. The original WRF I/O API was developed to provide access to layers implementing I/O and data formatting in a transparent package-independent manner. Model coupling has been added to the API specification in such a way that sending and receiving forcing data to coupled component models is semantically equivalent to reading and writing from I/O devices, an approach demonstrated by Coats *et al.* in the early-to-mid 1990s [4].

3. WRF/NCOM/SWAN Coupling through MCEL Implementation of API

The first reference implementation of the WRF I/O and Model Coupling API was implemented using the MCEL [2] to provide support for peer-to-peer coupled modeling systems of interacting components, referred to as L2-B style coupling in our original proposal: ad-hoc (not a priori scheduled), data-driven interactions between a relatively large number of components that produce data for their peers. This MCEL implementation was used to develop and test a prototype coupling of a subset High Fidelity Simulation of Littoral Environments (HFSoLE) CHSSI project [1]: the Navy Coastal Ocean Model (NCOM) and the Simulating WAves Nearshore (SWAN) wave model coupled with the WRF model.

The models were run for a coupled domain in the Gulf of Mexico off of the Louisiana and Mississippi shorelines. The 24-hour simulation period was November 7-8, 2002. The WRF model provided ten-meter winds through the I/O and Model Coupling API to MCEL at hourly intervals. MCEL filtered this data and produced wind stresses that are read by NCOM. NCOM, in turn, produced sea surface temperatures that were provided to WRF with a read through the API from an MCEL filter that interpolates the NCOM surface temperatures back onto the WRF grid. Results from WRF/NCOM, and WRF/SWAN 24-hour simulations are shown in Figure 1. Running WRF on 16 processes, NCOM on one process, the MCEL server on one process, and a

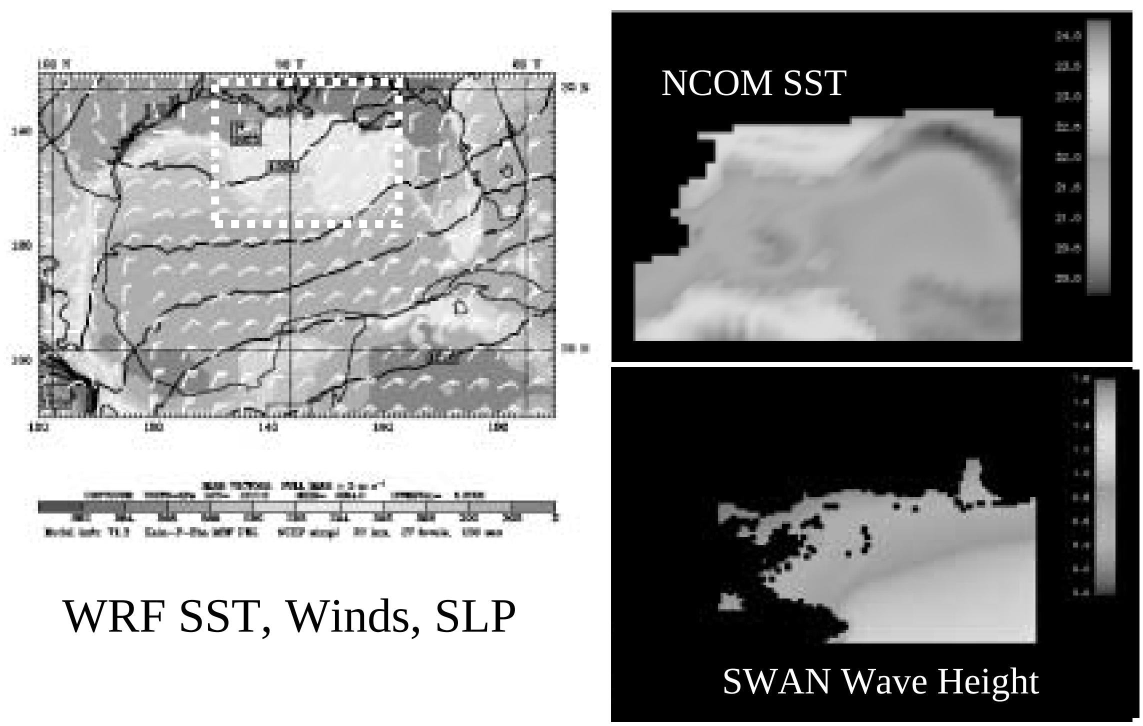


Figure 1. Output from the WRF and NCOM models after a 24-hour two-way coupled simulation. WRF provides lower level winds to NCOM; NCOM returns sea surface temperatures. The third plot shows output from SWAN, with one-way forcing from WRF lower level winds.

filter process on one process of on an IBM Power3 SP system (blackforest.ucar.edu), the total run time for the simulation was 1713 seconds, of which approximately seven seconds were used for inter-model coupling through the API. Thus, the overhead associated with the coupling through the MCEL implementation of the API is negligible.

4. WRF/ROMS Coupling through MCT Implementation of API

A second reference implementation of the WRF I/O and Model Coupling API was developed using the Model Coupling Toolkit (MCT) [5] to support regular, scheduled exchanges of boundary conditions for tightly to moderately coupled interactions (L2-A style coupling in our original proposal). This was used to couple versions of the WRF and Regional Ocean Modeling System (ROMS). WRF wind stress and heat fluxes were sent to the ocean model and sea-surface temperature were received from ROMS. Three performance benchmarks of the WRF/ROMS coupling were conducted. In addition, the L2-A coupled WRF/ROMS system is being used in follow-on scientific studies involving an idealized hurricane vortex described in [6].

4.1 Concurrent Coupling on a Single Machine

WRF was run for a 150x150x20 domain with a time step of 40 seconds; ROMS on a 482x482x15 domain with a time step of 240 seconds. WRF ran for 24 time steps and ROMS for four time steps on an Intel Linux cluster. The models exchanged boundary conditions every ocean time step. Table 1 shows the total run times of the main loop for each model and the times to send and receive data through the I/O and Model Coupling API. Time spent in the MCT implementation was less than 1% of the total run-time for each model. These results are worst-case, since such coupling is usually over intervals that are greater than every ocean time step.

PEs/ model	WRF main loop	WRF receive	WRF send	ROMS main loop	ROMS receive	WRF send
2	107.5	0.73	0.09	158.5	0.63	0.12
4	61.0	0.32	0.02	57.7	0.22	0.07
8	32.9	0.18	0.01	29.5	0.11	0.05
16	19.9	0.13	0.01	13.4	0.05	0.07

Table 1. Computational and concurrent coupling costs on a single parallel computer.

4.2 Concurrent Coupling using Two Machines over a Computational Grid

WRF and ROMS were coupled over a rudimentary computational grid. ROMS ran on one Intel Linux node located at the NOAA Pacific Marine Environmental Laboratory (PMEL) in Seattle, Washington; WRF on four Linux nodes located at the NOAA Forecast Systems Laboratory (FSL) in Boulder, Colorado. The Globus Toolkit [7] provided the grid middleware. Table 2 indicates that communication times were less than 2%.

WRF main loop	WRF receive	WRF send	ROMS main loop	ROMS receive	WRF send
248.0	4.74	0.04	171.0	2.69	1.49

Table 2. Computational and concurrent coupling costs over the Grid.

4.3 Sequential Coupling on a Single Machine

WRF and ROMS were coupled sequentially on four Linux nodes at FSL. Again, as indicated in Table 3, the costs of the MCT implementation communication and interpolation were small.

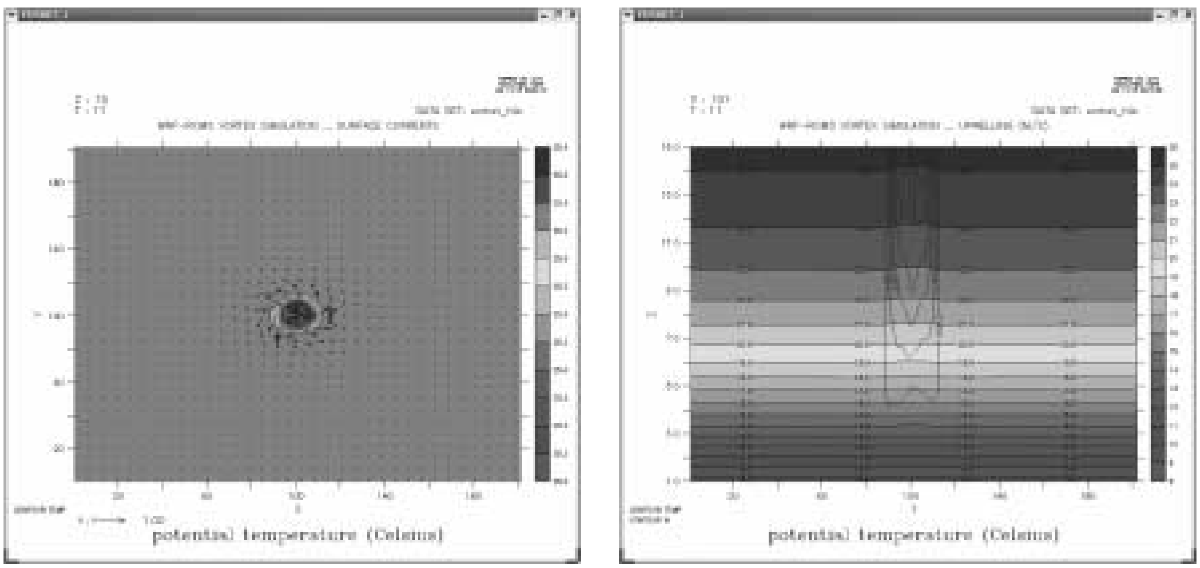
PEs/ model	WRF main loop	ROMS main loop	WRF send	ROMS main loop	ROMS receive	WRF send
4	82.0	0.10	0.02	59.8	0.27	0.11
8	47.8	0.10	0.05	33.1	0.16	0.09

Table 3. Computational and coupling costs for sequentially coupled WRF/ROMS.

4.4 WRF/ROMS Simulation of Idealized Hurricane

This coupling scenario is part of a project studying the physics of hurricane development by investigators at the University of Miami, the University of Washington [6], and the Model Environment for Atmospheric Discovery (MEAD) project [9], National Science Foundation (NSF)-funded project at the National Center for Supercomputing Alliance (NCSA). The WRF atmospheric domain was 161 by 161 horizontal points and 30 levels spanning a 1288 km grid initialized to a "background" sounding representing the mean hurricane season in the Caribbean. The ocean domain is 200 by 200 horizontal points by 15 in the vertical, and initialized with temperature stratification typical of the tropical Atlantic. WRF provided wind stress to the ROMS, and the resulting ROMS sea-surface temperature was fed back to WRF. WRF and ROMS were time-stepped at one-minute, and five-minutes respectively, and coupled every 10 minutes. Output was at 30-minute intervals. The load balancing for this concurrent run required eight processors modeling the atmosphere for every oceanic processor.

Figure 2a shows divergent wind-driven surface currents providing an upwelling of cold water centered at the vortex core, with marked asymmetrical structure. This anisotropy affects the convective perturbations in the atmosphere that drive the vortex generation. Figure 2b shows the temperature stratification in the ocean, as well as the vertical velocity field.



Figures 2a, b: Output from WRF/ROMS coupled simulation of simulated hurricane vortex using MCT implementation of I/O and Model Coupling API, courtesy of Chris Moore, NOAA Pacific Marine Environment Laboratory.

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